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# Survey of Maximum Power Point Tracking Techniques for Photo-Voltaic Array

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***Abstract***

*In order to increase the output power of photo-voltaic power generation rapidly and accurately, it is necessary to track output of the maximum power. This paper summarizes the methods of Maximum Power Point Tracking (MPPT), and points out the limitations and notes of the MPPT methods. Meanwhile, the double perturb-and-observation method and iterative comparison method are elaborated in this paper. Finally, the study direction in the future is prospected.*

***Keywords****: maximum power point tracking (MPPT), maximum power point (MPP), photo-voltaic (PV)array, photo-voltaic power generation*

## 1. Introduction

With the rapid development of social economy and growing energy needs, conventional energy is more and more demand. Meanwhile, the extensive use of conventional energy sources caused the world within the scope of the environmental pollution and ecological deterioration. Development and application of new energy become the inevitable trend of world development. Solar energy with its green, no pollution, no noise and other unique advantages has became one of the most promising and important new energy sources of all the renewable energy. The solar cell is a kind of nonlinear components, the maximum power point voltage will changes with the change of light intensity and environment temperature. In order to improve the conversion efficiency of solar cells, it is necessary to track output of the maximum power [1-2].

This paper based on the solar cell model and its output characteristic, common maximum power point tracking (MPPT) control methods of photo-voltaic power generation system and compare characteristics of each kind of control methods. Paper development direction of MPPT control methods is pointed out in future.

## 2. The Model and Characteristics of Photo-Voltaic Cells

### 2.1. The Model of Photo-Voltaic Cells

In order to study the work characteristics of photo-voltaic cells and the factors that influence its efficiency, the equivalent circuit needs to be analyzed, According to the working principle and the internal characteristics of photo-voltaic cells, the photo-voltaic cell simulation of equivalent circuit was given in Figure 1.

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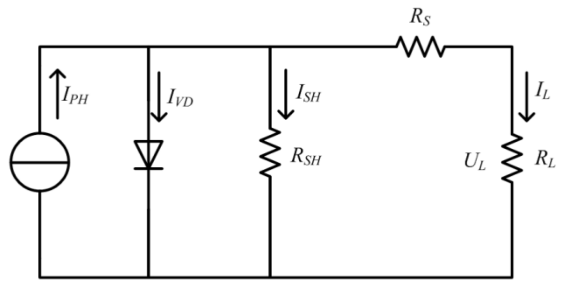


**Figure 1. The Photo-Voltaic Cell Simulation of Equivalent Circuit**

Where $R_L$ represents the external load of photo-voltaic cell, $U_L$ the load voltage (output voltage), $I_L$ the load current (output current). Where $R_S$ represents the series resistance consist of internal resistance and electrode resistance, generally less than 1 Ω, $R_{SH}$ the leakage resistance, generally larger, about a few thousand Ω. There for to simplify analysis procedure, $R_S$ and $R_{SH}$ can be ignored. Where $I_{VD}$ represents the electric current flow past equivalent diode, which was called diffusion current or dark current, $I_{PH}$ the photo-generated current, $I_{PH}$ is in direct proportion to the area of photo-voltaic cell, illumination intensity and temperature, when the sunlight intensity is constant, $I_{PH}$ can be thought of as a constant current source.

The current-voltage equation is:

$$I = I_L - I_0\{\exp[\frac{q(V+R_S)}{AKT} - 1]\} - \frac{V+IR_S}{R_{sh}} \quad (1)$$

Where I represents load current, A; $I_L$ the photo-generated current, A; $I_0$ the reverse saturation current, A; A the Diode factor; q the electron charge, $1.6\text{x}10^{-19}$C, T the junction temperature; R the series resistance, Ω; $R_{sh}$ the parallel resistance, Ω.

It can be known from the analysis of the mathematical model of photo-voltaic cells, the output voltage and output current of photo-voltaic cell is complex variable change with temperature and illumination intensity. The U-I characteristic curve of photo-voltaic cell was given in Figure 2.

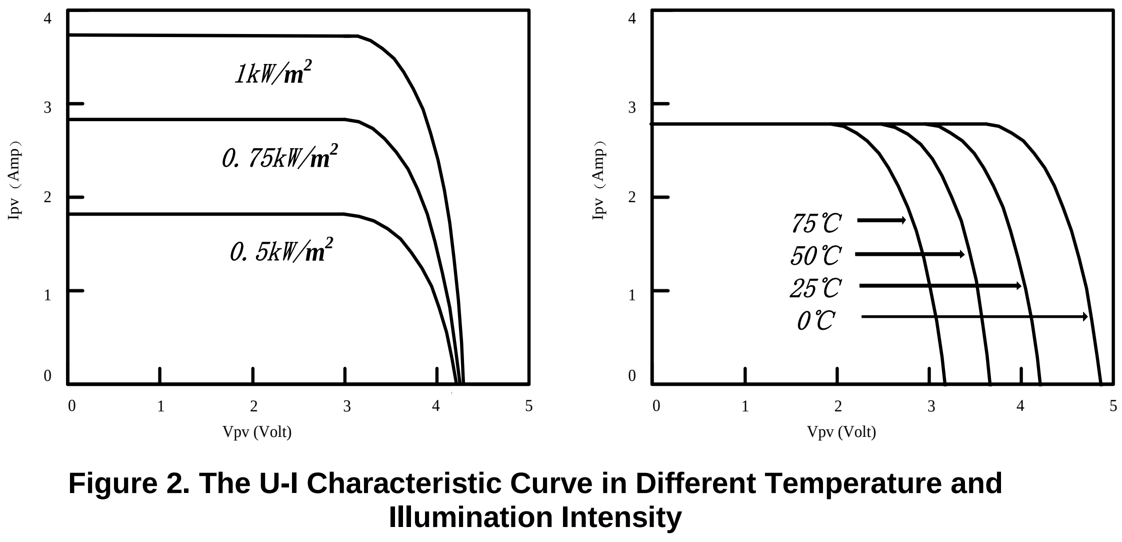


**Figure 2. The U-I Characteristic Curve in Different Temperature and Illumination Intensity**

By observe the characteristic curve, it can be seen that the output voltage and output current of photo-voltaic cell has very obvious nonlinear characteristics. The output current is almost the same, When the output voltage is very low, which can be regarded as a dc constant current power supply.

 

The P-U characteristic curve of photo-voltaic cell was given in Figure 3.

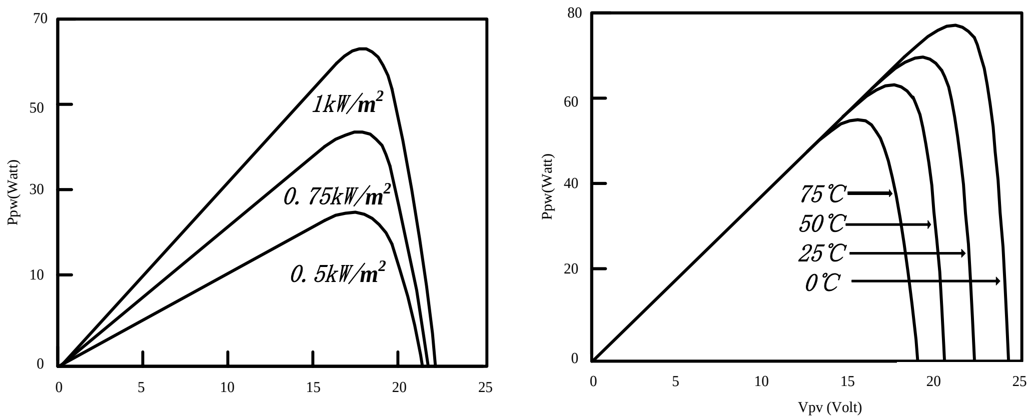


**Figure 3. The U-I Characteristic Curve in Different Temperature and Illumination Intensity**

Based on P-U characteristic curve and the analysis of the mathematical model of the photo-voltaic cells may safely draw the conclusion, the P-U curve of photo-voltaic cell is a single peak curve, The output power of photo-voltaic cells showed a trend of decrease after the first increase, So in a specific environment static conditions exist a unique maximum power point(MPP). In the actual application condition of natural light radiation intensity and atmospheric transmittance are in dynamic change, In order to acquire electric energy as much as possible under the same sunshine intensity and cell junction temperature, have the maximum power point tracking.

## 3. The Maximum Power Point Tracking Methods

### 3.1. Basic Method

#### 3.1.1. Constant Voltage Tracking Method

Constant voltage tracking method [3-4] is also called the voltage feedback method, It is a simplified method of maximum power point tracking control, stable voltage control is used to approximately achieve maximum power point tracking. According to the photo-voltaic cell P-U characteristic curve can be obtained, when the photo-voltaic cell temperature conditions are the same, to different light conditions, the maximum power output of photo-voltaic battery point total approximate near a particular voltage $U_m$ . As long as guaranteeing photo-voltaic array can make constant output voltage in the case of constant temperature, PV array can work near the maximum power point in this temperature. The maximum power point tracking system can be similar to a regulated system.

Constant voltage method is characterized by implementing simple and stable performance, but it ignore the effects of the environment temperature and photo-voltaic array itself temperature to the output voltage of photo-voltaic array, its essential approach is not really the maximum power point tracking methods. For the four seasons temperature difference and temperature difference between day and night change larger areas, constant voltage tracking method cannot track the maximum power at all temperatures.

 

### 3.2. The Maximum Power Point Tracking Control Based On Photo-Voltaic Array Mathematical Model Optimization

#### 3.2.1. Open circuit Voltage Proportional Coefficient Method

In order to overcome the effects of ambient temperature and PV array temperature, constant voltage tracking method is improved to open circuit voltage proportional coefficient method. [5-9]It can be obtained by the external characteristic of photo-voltaic cells that $U_{MPP}$ with $U_{OC}$ change proportionately when $U_{OC}$ with ambient temperature and light intensity change.

$$U_{MPP} \approx k_1 U_{oc} \tag{2}$$

Where $k_1 < 1$ is Open circuit voltage ratio; $U_{OC}$ to $U_{MPP}$ unit. $U_{OC}$ the open-circuit voltage, which can be measured by disconnecting photo-voltaic battery and load periodically. This method have simple theory, but $k_1$ is different in different photo-voltaic array, between 0.7 to 0.8 [9].

The open circuit voltage proportional coefficient method have Simple construction, can be implemented by cheap analog circuit, and it will not reverberate near the maximum power point, the result has strong anti-interference ability. But formula (2) is an approximate formula, and the proportionality coefficient is different in different photo-voltaic array, the photo-voltaic array is not working on the real maximum power point, to measure $U_{OC}$ needs to disconnecting photo-voltaic battery and load periodically, it will cause the instantaneous power loss.

#### 3.2.2. Short Circuit Current Ratio Coefficient Method

It can be obtained by the external characteristic of photo-voltaic cells that $I_{MPP}$ with $I_{SC}$ change proportionately when $I_{SC}$ with ambient temperature and light intensity change.[5-9]

$$I_{MPP} \approx k_2 I_{SC} \tag{3}$$

Where $k_2 < 1$ is short circuit current ratio; $I_{SC}$ to $I_{MPP}$ unit, $I_{SC}$ the short circuit current, its measuring method is more complicated than $U_{OC}$. $I_{SC}$ can be measured by joining the switch in inverter to short-circuit photo-voltaic array periodically. $k_2$ is different in different photo-voltaic array, about 0.86.[9]

Short circuit current ratio coefficient method have same advantages and disadvantages formula (3) is an approximate formula, and the proportionality coefficient is different in different photo-voltaic array, the photo-voltaic array is not working on the real maximum power point.

#### 3.2.3. Curve-Fitting Method

Curve-fitting method is on the basis of the P-U characteristic curve of photo-voltaic array, to constantly sampling the photo-voltaic battery output voltage U and current I, create a similar circuit model with the biggest known working point curve fitting equation directly.

Curve fitting method only need to constant voltage and current sampling and correction obtains the reasonable parameters, but in the process of fitting it need for a large amount of calculation, cannot play the quickness of mathematical model.

We can prestablish parametric model and store in the data in the table in the project, and choose different parameter according to actual situation when it works. MPPT control by look-up table data to be obtained. Look-up table method can effectively solve the problem of the quickness of curve fitting, But need to build huge data form and stored in advance.

### 3.3. The MPPT Method Based on Perturbation

Perturbation method is one of the most studied and one of the most commonly used maximum power point tracking control method. This kind of method does not detect the change of external environment, just directly measure the voltage and current of PV arrays to complete the maximum power point tracking control.

#### 3.3.1. Perturbation and Observation Method

Perturbation and observation method also[10-14] known as mountain climbing method, is one of the most studied and one of the most commonly used maximum power point tracking control method. Its fundamental is: add disturbance of PV array output voltage Periodically, and true time detect PV array output power. Compare with the last cycle of the output power, correct the direction of the next cycle of disturbance quantity. If the PV array output power increase, add the same direction disturbance to the next cycle of output voltage Continue, otherwise, change the direction of adding disturbance.The algorithm flow chart as follows:

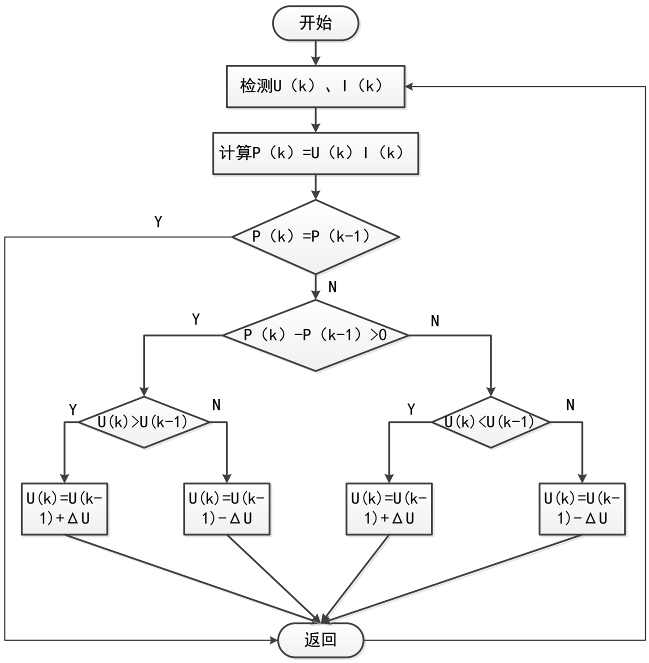


**Figure 4. The Algorithm Flow Char of Perturbation and Observation Method**

By constantly looking for and close to the maximum power point of PV array, until the output power near the small range of maximum power point of repeated shocks to achieve dynamic balance. Perturbation method has simple structure, less measured parameters and easy to implement,it is a really maximum power point tracking methods, so it is widely used.There are also some disadvantages:

(1) Due to add perturbation and to be revised constantly, the end result is the PV cells working point is near the maximum power point swings back and forth, can not stable in the maximum power point.

(2) Disturbance step length determines the speed of tracking system, the faster the perturbation step length is, the greater the tracking is, however the system tracking

precision is reduced, while small perturbation step size bring higher tracking precision of the system, racking speed slower and could make the PV array for a long period of time working in low power area, it will cause power loss.

(3) When the external environment change relatively severe, perturbation and observation method may cause power loss, even erroneous judgement, the PV array can not work in the maximum power point.

### 3.3.2. Conductance Increment Method

By the P-U characteristic curve of PV array, When PV array working in the maximum power point. P-U curve slope is zero, have the following criteria:

$$\begin{cases} \frac{dP}{dU} = 0, \text{Working on the maximum power point;} \\ \frac{dP}{dU} > 0, \text{Working on the left of the maximum power point;} \\ \frac{dP}{dU} = 0, \text{Working on the right of maximum power point} \end{cases} \quad (4)$$

And $P = UI$ calculate0 derivative at both ends to $U$ :

$$\frac{dP}{dU} = \frac{d(UI)}{dU} = I + U\frac{dI}{dU} \quad (5)$$

conductance increment method [15-20]is to set a value changes on the output voltage of photo-voltaic array to determine the current work on what side of the MPPT of photo-voltaic array. When it work on the right side of the MPPT, change value is negative, otherwise, change value is positive. Transition from one steady state to another, true judgment will be made, ultimate stable within the neighborhood of MPPT. The algorithm flow chart as follows:

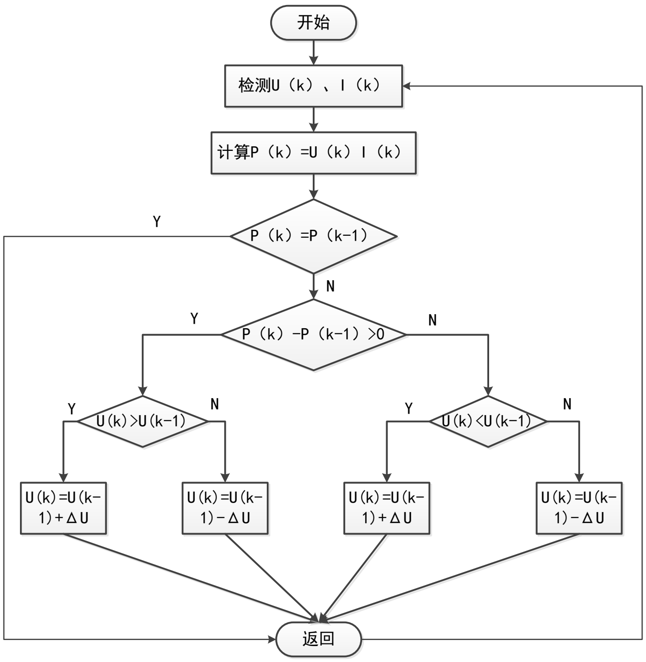


**Figure 4. The Algorithm Flow Char of Conductance Increment Method**

Incremental conductance method track maximum power point by dynamic changing photo-voltaic array output voltage. Its main characteristic is high control accuracy and good stability, has nothing to do with the photo-voltaic array output characteristic and parameters. In the case of the external environment is relatively stable, incremental conductance method has a good stability control, When the external environment mutation, the system can fast track to the MPP, has a good dynamic characteristic.

But the incremental conductance method has problem in step length and the threshold value. For the larger step tracking speed is fast, error is larger, and near the maximum power point vibration, photo-voltaic array may not work in the maximum power point. Small step will reduce the response speed of the system, tracking speed is slow. Incremental conductance method need to give a proper threshold in practice $E$, when $dP/dU = \pm E$ System work in maximum power point. No longer change working point voltage when the change is less than the threshold value. In theory, threshold as small as possible, the smaller, the greater the working point of the last close to the maximum power point. But in the actual threshold is set too small will never reach to a stable system, finally lead to within a certain range of oscillation.

A lot of reference put forward improvement measures about the shortage of the incremental conductance method. conductance increment method use $dP/dU$ variable step size directly adjusting the duty ratio was proposed in reference[16]. The area is divided into constant current source area and constant voltage source area according to the U-I characteristic curve, by measuring the size of the current rate of change to variable step length, this method was proposed in reference [17]. But in the actual photo-voltaic system of multiple peak power would happen, Incremental conductance method of photo-voltaic array MPPT algorithm is trapped in local minimum point. Using particle swarm optimization algorithm can accurately track the maximum power point quickly [18].

### 3.4. The Maximum Power Point Tracking Control Based on Artificial Intelligence Processing Method

#### 3.4.1. The Fuzzy Logic Control Method

Fuzzy logic control method [21-22] is a kind of MPPT control method based on fuzzy logic. For the fuzzy logic is usually to be 3 steps, fuzzification, evaluation of control rules, solving ambiguity. According to the characteristics of photo-voltaic array. $dP/dU = 0$ in the maximum power point, the method used in the photo-voltaic system error of the input variables and input variables can be set to:

$$\begin{cases} E(n) = \dfrac{P(n) - P(n-1)}{U(n) - U(n-1)} \\ \Delta E = E(n) - E(n-1) \end{cases} \tag{6}$$

Where $P(n)$ is output power, $U(n)$ the output voltage. $E(n) = 0$, when PV array working in the maximum power point. Because of the MPPT algorithm is eventually to get a precise control, fuzzy output turn into a precise output through membership function.

Expert experience and control theory is represented as language control rules by fuzzy control. Fuzzy control tracking fast, can effectively overcome the nonlinear and time lag of photo-voltaic system, would not have fluctuation when reach the maximum power. But the design of the fuzzy control link is more complicated, the precise definition of fuzzy set and set the shape of the membership functions and control rules table is difficult point in design. Need design personnel have more intuition and experience, and the experiment of accumulation for a long period of time.

 

### 3.4.2. The Neural Network Method

Neural network control method [23-24] based on neural network, commonly used neural network structure is included input layer, hidden layer and output layer, as is shown in Figure 5:

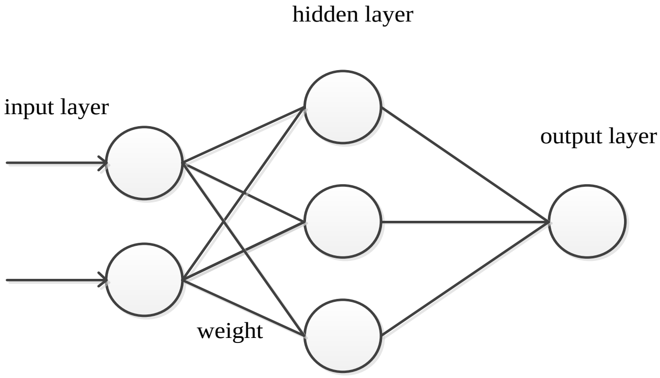


**Figure 5. Neural Network Control**

Where, the number of network nodes are 2, 3, 1 respectively. It can be the parameters of the PV array, external environment parameters such as light intensity temperature, also can be the synthesis, when applied to the PV array. The output signal can be output voltage after optimization the inverter duty ratio control signal, *etc*. Between all nodes in the neural network has a weight gain, arbitrary continuous input function can be transformed to any desired output function by choosing appropriate weights. So as to realize the maximum power point tracking of photo-voltaic array.

The focus of the neural network is the need to design appropriate weight gain. Proper weight to the neural networks gain is needed for training. This training need to use a lot of input and output sample. Due to the different of photo-voltaic array parameter, for different PV array need to targeted training, need to spend a lot of time. Compared with the simple look-up table function, the neural network, not only can make the input and output of the training sample match exactly but interpolation and a certain number of input and output of extrapolation model also can achieve matching.

## 4. Conclusion

In addition to the MPPT control method of mentioned in this paper, a lot of literature puts forward many other MPPT control. As a result of the MPPT purpose is to maximize the output power of PV array, when the photo-voltaic array connected with inverter, this problem can be converted to maximize on the inverter output power; Reference [26] combine open circuit voltage disturbance observation method with perturbation and observation method to solve fast and accurate tracking problem when the outside light conditions change.

Due to Photo-voltaic cells with nonlinear characteristics, and the influence of external conditions on the control the maximum power point tracking problem become a very complex and comprehensive issue. Through the above analysis it can be seen that tracing method has its advantages and inevitably has some drawbacks. Along with the advance of mathematical analysis and intelligent method, for the PV array maximum power point tracking algorithm provides a rich theoretical basis and new ideas. How to make all kinds of maximum power point tracking control method for organic combination, complement each other is the future research direction of the PV array maximum power point tracking control. With the vigorous development of the solar energy and other renewable energy use, the implementation method and simplified and improving tracking speed and tracking accuracy of PV array maximum power point tracking technology is the inevitable trend of the development of the future.

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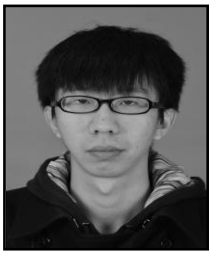

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